Cadaveric Testing of a Novel Scapholunate Ligament Reconstruction

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Abstract

Background Existing scapholunate interosseous ligament (SLIL) reconstruction techniques include fixation spanning the radiocarpal joint, which do not reduce the volar aspect of the scapholunate interval and may limit wrist motion.

Questions/Purpose This study tested the ability of an SLIL reconstruction technique that approximates both the volar and dorsal scapholunate intervals, without spanning the radiocarpal joint, to restore static scapholunate relationships.

Materials and Methods Scapholunate interval, scapholunate angle, and radiolunate angle were measured in nine human cadaveric specimens with the SLIL intact, sectioned, and reconstructed. Fluoroscopic images were obtained in six wrist positions. The reconstruction was performed by passing tendon graft through bone tunnels from the dorsal surface toward the volar corner of the interosseous surface. After reduction of the scapholunate articulation, the graft was tensioned within the lunate bone tunnel, secured with an interference screw in the scaphoid, and sutured to the dorsal SLIL remnant. Differences among testing states were evaluated using repeated measures ANOVA.

Results There was a significant increase in the scapholunate interval in all wrist positions after complete SLIL disruption. Compared with the disrupted state, there was a significant decrease in scapholunate interval in all wrist positions after reconstruction using a tendon graft and interference screw.

Conclusion Our SLIL reconstruction technique reconstructs the volar and dorsal ligaments of the scapholunate joint and adequately restores static measures of scapholunate stability. This technique does not tether the radiocarpal joint and aims to optimize volar reduction.

Clinical Relevance Our technique offers an alternative option for SLIL reconstruction that successfully restores static scapholunate relationships.

Keywords
- scapholunate ligament
- reconstruction
- SLIL
- ligament
- wrist

Although many techniques for scapholunate interosseous ligament (SLIL) reconstruction have been described, there is still uncertainty as to which technique should be used.[1] Given the consequences of instability and degenerative arthrosis after chronic scapholunate (SL) dissociation, a reconstruction technique that effectively and most closely recreates the normal static and dynamic relationships of the scaphoid and lunate is needed. Soft tissue reconstruction techniques include dorsal capsulodesis,[2–6] the four-bone ligament reconstruction by Almquist et al,[7] the reduction and association of the scaphoid and lunate (RASL) procedure,[8] the scapholunate axis method (SLAM),[9] Brunelli's tendon weave,[10] and its modification.[11]

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Most have reported acceptable clinical results and patient satisfaction despite radiographic deterioration. No technique is able to restore normal anatomy and kinematics, and all are at risk for diminished postoperative range of motion (ROM) and grip strength.[12–15] This may be attributable to the unavoidable biologic effect of performing surgery in an anatomic area susceptible to scar formation and adhesions. A capsular flap or tendon graft that spans and tethers either the radiocarpal[10] or intercarpal joint (such as the dorsal radiolunatetriquetral ligament as described in Brunelli's modification)[11,13,15] may also contribute to postsurgical stiffness and subjective weakness that result from the lost mobility. One limitation of the available reconstruction procedures specific to the dorsal aspect of the wrist joint is an inability to stabilize and sufficiently reduce the volar SL articulation.[10] While the dorsal SLIL has traditionally been the primary focus of reconstruction techniques,[16] recent biomechanical[17–19] and clinical[20,21] investigations suggest greater relative significance of the volar SLIL ligaments in addition to the dorsal fibers than has been previously reported and particularly when the wrist is axially loaded in extension.[22,23]

Clinical and in vitro studies indicate that the modified Brunelli's technique (MBT) results in favorable ROM and wrist biomechanics.[11–15,24–29] In addition, technological innovation has made available new implants and devices, such as interference screws and the SLAM device[9] that provide alternative methods to achieve soft tissue fixation and graft positioning and tensioning within bone and across joints. With data from clinical and in vitro reporting of the MBT and from previously reported techniques of scapholunate ligament reconstruction with ligament augmentation,[30] we hypothesized that reconstruction with a graft that spans the scapholunate joint with internal fixation in the scaphoid creates an anchor for the construct that can achieve both strength and elasticity to permit multiplanar motion while enabling optimal wrist mobility. We have developed a SLIL reconstruction technique that approximates the volar and dorsal SL intervals without spanning the radiocarpal joint and uses an interference screw to enhance fixation at the bone–tendon interface. In this investigation, we performed cadaveric testing to determine whether this reconstructive technique could restore and maintain static scapholunate relationships.

Materials and Methods

Nine human fresh frozen upper extremity cadaveric specimens were prepared for this experiment. The specimens were disarticulated at the elbow joint, leaving the proximal radioulnar joint and forearm intact. There was no radiographic or physical evidence of injury or degenerative disease of the wrist or forearm. The specimens were prepared and tested using the same protocol reported by Pollock et al.[25] The tendinous portions of the flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), all finger flexors, extensor carpi radialis longus (ECRL) and brevis (ECRB), and extensor carpi ulnaris were exposed using midline volar and dorsal approaches. Interlocking no. 5 Ethibond sutures were placed into FCR, FCU, and ECU. The ECRB and ECRL tendons were sutured together, and a side-to-side suturing technique was used to grasp all finger flexors. The midline forearm incisions were closed using a running nylon suture.

External fixator pins (5 mm) were introduced into the intramedullary canal of the radius and ulna in an antegrade fashion. A transverse 5 mm external fixator pin was also inserted into the distal radius. The insertion of these external fixator pins allowed the forearm to be mounted in a vertical orientation, with external fixator bars secured to threaded pins inside a customized testing cart (►Fig. 1). The suture loops (attached to the forearm tendons) were passed through drill holes at the base of the testing platform. Small metal hooks were attached to the suture loops, allowing the application of weighted plates to the forearm tendons. To create wrist flexion, a 700-g load was applied to the FCR and a 200-g load to the FCU. To create wrist extension, 600-g loads were applied to the combined ECRB/ECRL tendons and to the ECU, each. To create radial deviation (RD), a 600-g load was applied to the FCR and a 650 g-load applied to the combined ECRB/ECRL tendons. To create ulnar deviation (UD), a 225-g load was applied to the FCU and a 1-kg load applied to the ECU. To create a clenched fist position, a 650-g load was applied to the combined finger flexor tendons, while a 375-g load was applied to the ECU and a 575-g load was applied to the combined ECRL/ECRB tendons to maintain the wrist in 20 degrees of extension. These load amounts do not exactly match those used by Pollock et al,[25] as we found that different amounts of weights were required to create the appropriate wrist and finger motion.

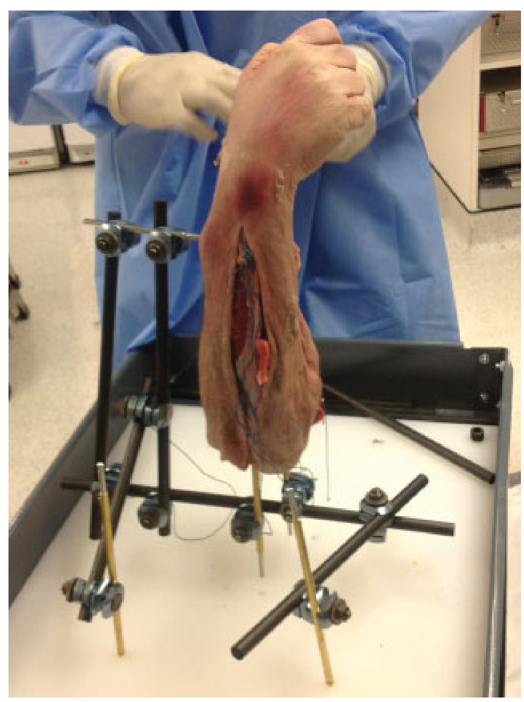

Fig. 1 External fixator used for suspension of weights to allow positioning of wrist during radiographs. External fixator bars are secured to threaded pins inside the customized testing cart. The suture loops (attached to the forearm tendons) were passed through drill holes at the base of the white testing platform. Not pictured: Small metal hooks were attached to the suture loops, allowing the application of weighted plates to the forearm tendons.

Fluoroscopic posterior–anterior (PA) and lateral images were taken with the wrist in each of the aforementioned positions and the forearm in neutral. The protocol for positioning the wrist to obtain these radiographic images was performed as described by Pollock et al.[25] To maximize reproducibility, the testing apparatus (and not the fluoroscope) was rotated 90 degrees to obtain the orthogonal images, with markings made on the floor to aid in positioning of the testing apparatus. Additionally, all further dissection and reconstruction techniques were performed without removing the specimen from the upright position on the testing apparatus. The SL interval was measured from the PA image at its midportion (at the level of the flat medial facet of the scaphoid). This was measured using ImageJ (NIH) software, which has an accuracy of one-tenth of a millimeter. A radiopaque marker of known diameter was used for calibration in all PA images. The SL and radiolunate angles were measured from the lateral image using a goniometer with the smallest unit of measurement of 1 degree.

There were three testing states in this experiment: intact, SLIL instability, and after SLIL reconstruction. After obtaining the fluoroscopic images for the intact testing state, the specimen was kept in the upright position and a dorsal approach to the wrist was performed. Using 2.5× loupe magnification, the third dorsal compartment of the wrist was entered, and the extensor retinaculum was divided longitudinally. A longitudinal capsulotomy was performed, centered over the SL interval. The SLIL was visualized and its dorsal, membranous, and volar components were transected sharply using a no. 15 scalpel blade. The volar radioscaphocapitate ligament was also sharply transected to allow creation of grossly apparent static SL instability.[24] The capsule and extensor retinaculum were closed with simple interrupted sutures. Fluoroscopic testing was repeated.

The sutures were removed from the extensor retinaculum and dorsal capsule in preparation for the SLIL reconstruction. A palmaris longus tendon (or the extensor indicis proprius when the palmaris longus was not present, which occurred in two specimens) was harvested for use in the reconstruction. The distal 4 cm of the palmaris longus tendon provides the ideal graft width and length. Sutures were applied to the tails of the graft to aid in manipulation, and the graft was stored in saline-soaked gauze during tunnel preparation. Single 0.062-inch Kirschner wires (K-wires) were inserted into the scaphoid and lunate to aid in bony manipulation (smaller sized K-wires to manipulate the bone while performing the procedure in vivo to avoid obstruction of the path of the interference screw and iatrogenic fracture from the K-wire hole are equally acceptable so long as sufficient purchase of the joystick can be maintained to perform the desired manipulation). A guide wire for a cannulated 3.2-mm drill was placed along the dorsal surface of the scaphoid, with the edge of the guide positioned 3.2 mm from the scapholunate joint and midway between the proximal and distal aspects of the scaphoid (as localized on a PA fluoroscopic image). Wire positioning was directed toward the volar corner of the interosseous surface of the scaphoid to ensure that the tunnel exited within the volar aspect of the scapholunate joint. The cannulated 3.2-mm drill was used over the guide wire to create the first bone tunnel. A matching tunnel on the lunate was created starting from the most dorsally prominent surface of the lunate and at the same proximal–distal level as the scaphoid tunnel. The site of tunnel entry was positioned, with the edge of the guide wire positioned 3.2 mm lateral to the articulating surface of the lunate, with the scaphoid and angled toward the volar aspect of the interosseous surface of the lunate. Because the drill bit that was used with this system had a larger diameter than those commonly used for headless screw fixation or stabilization for the carpus, the required distance of 3.2 mm from the scapholunate joint for drill placement was chosen to decrease the risk of tunnel fracture. A smaller drill bit diameter between 2 and 3 mm was considered to be adequate and could first be tried to minimize the risk of fracture. Direct visualization was used to avoid violation of the lunocapitate and radiolunate articular cartilage. Using a suture loop passer, a tagging stitch on the tendon graft was passed through the lunate in a dorsal-to-volar direction. The tendon graft was then delivered through this tunnel. The suture loop passer was then used similarly to pass the tagging stitch and tendon through the scaphoid in a volar-to-dorsal direction. A Keith needle was used in the first four specimens because the suture loop passer was not available. The SL articulation was reduced using K-wires placed into the scaphoid and lunate as joysticks for bony manipulation. SL joint reduction was temporarily held with an additional transverse K-wire (placed distal to the bony tunnels). The graft was held in tension across the SL joint by an assistant pulling on sutures attached to the ends of both limbs of the graft. To maintain tension on the graft and achieve fixation of the bone–tendon interface, a 3 × 10 mm interference screw was inserted into the scaphoid from dorsal to volar and flush to the bone in the scaphoid (►**Fig. 2**). This interference screw had a diameter consistent with headless screws used for standard scaphoid fixation. To create an additional intercarpal soft tissue tether to maintain and hold the SL joint reduced, the limbs of the graft were sutured to each other (one limb proximal and one limb distal) on the dorsal surface of the SL articulation with two horizontal mattress sutures (braided, nonabsorbable 3–0 sutures). Excess graft length was then trimmed.

Repeated measures analysis of variance, as was used by Pollock et al,[25] was used to evaluate differences among the three testing states (intact, torn, and reconstructed) with pairwise comparisons between testing states, i.e., intact versus torn, torn versus reconstructed, and intact versus reconstructed. Statistical analysis was performed with SPSS 19.0 (IBM; Armonk, NY). The level of statistical significance was defined with an α level of $p < 0.05$.

Results

The SL interval significantly increased in all wrist positions following SLIL tear (compared with intact, $p < 0.01$) and significantly decreased after reconstruction (compared with torn, $p < 0.01$). In the clenched fist position, the mean SL interval was 1.7 mm in the intact SLIL; 2.9 mm in the torn SLIL; and 1.8 mm in the reconstructed SLIL (►**Fig. 3**). The differences between the intact and torn SLIL ($p < 0.01$) and

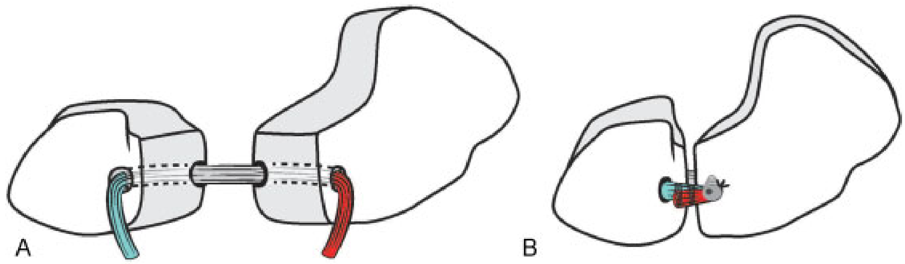

Fig. 2 Scapholunate ligament reconstruction technique. The lunate is on the left and the scaphoid is on the right. (A) The palmaris tendon graft is passed through the lunate in a dorsal-to-volar direction (blue) and through the scaphoid in a volar-to-dorsal direction (red). (B) The scapholunate articulation is reduced, and the graft is held in tension while a 3×10 mm interference screw is inserted flush to the dorsal surface of the scaphoid. The limbs of the graft are secured along the dorsal surface of the SL articulation with braided, nonabsorbable 3–0 sutures. SL, scapholunate.

the torn and reconstructed SLIL ($p < 0.01$) were statistically significant; there was no statistically significant difference between the intact and reconstructed SLIL.

The SL angle significantly increased in neutral, flexed, and RD positions following SLIL tear (compared with intact, $p < 0.05$). The SL angle increased 7 degrees the UD position following SLIL tear but did not reach significance. There was no significant change in the extended, UD, or clenched fist positions following SLIL tear. Following SLIL reconstruction, the SL angle significantly decreased in the flexion, RD, and UD positions (compared with torn, $p < 0.05$). In the flexion position, the mean SL angle was 66 degrees in the intact state; 75 degrees in the torn state; and 62 degrees in the reconstructed state (intact vs. torn, $p < 0.05$; torn vs. reconstructed, $p < 0.05$; intact vs. reconstructed $p > 0.05$; ►**Fig. 4**).

The radiolunate angle increased in neutral, flexed, and extended positions following SLIL tear (compared with intact, $p < 0.05$) but did not significantly change in the RD, UD, or clenched fist positions following SLIL tear. The decrease in radiolunate angle after reconstruction was significant in extension ($p < 0.05$) and approached significance in neutral ($p = 0.05$) and flexion ($p = 0.06$, ►**Fig. 5**). No tunnel fractures or propagation of fracture lines in the scaphoid or lunate was seen on review of final fluoroscopic images.

Discussion

Our data indicate that our reconstruction technique restores the static SL relationship in the coronal plane in all positions and in the sagittal plane in flexion, RD, and UD. While further in vivo investigation is needed to determine the exact clinical utility and appropriateness of this technique, our experiment provides the "proof of concept" necessary to continue refining a technique to restore the complex relationship of the scaphoid and lunate without limiting wrist motion.

Seeking to improve the existing techniques, our reconstruction incorporates two main concepts: (1) avoiding tethering the radiocarpal joint and (2) including the volar aspect of the SLIL in the reconstruction. Previously described reconstruction techniques can provide sufficient patient satisfaction, but

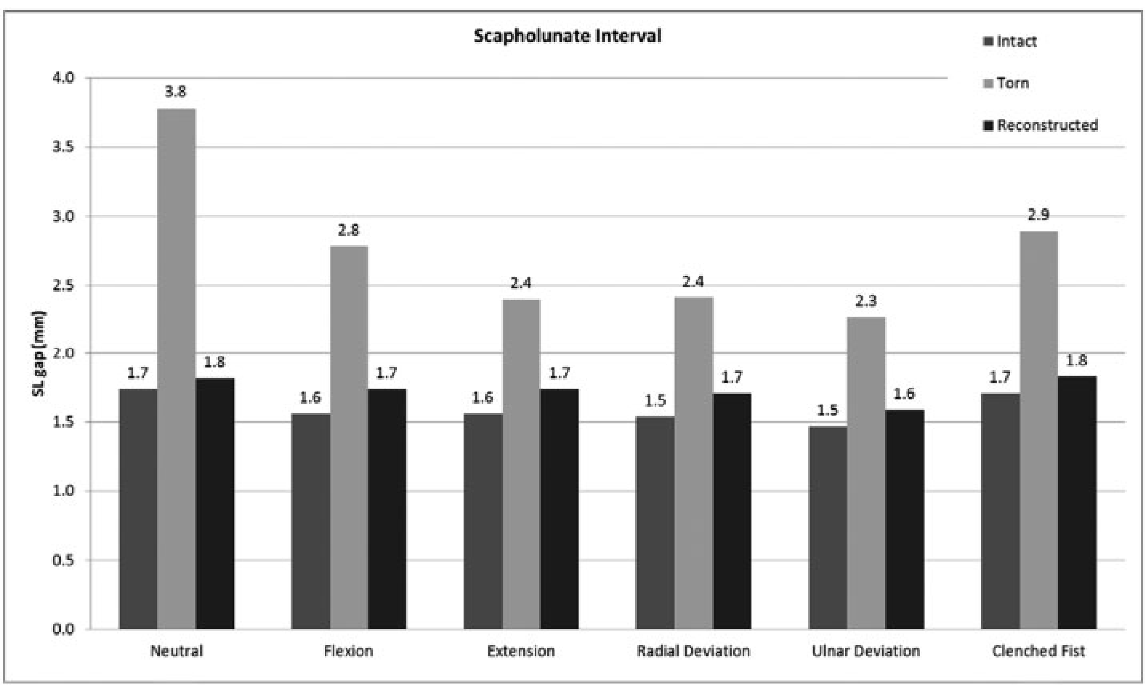

Fig. 3 Average scapholunate interval for all conditions and positions (mm).

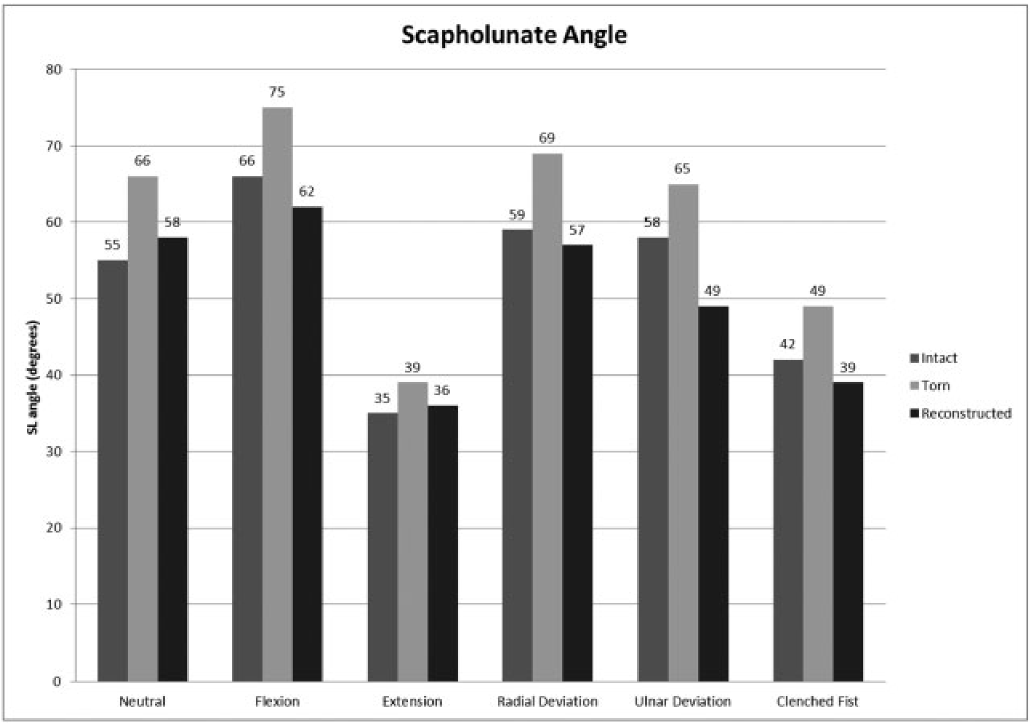

Fig. 4 Average scapholunate angle for all conditions and positions (degrees).

expectations for recovery include limits in postoperative wrist ROM and grip strength. While the soft tissue interference screw used in the current technique does not affect the tension of the reconstruction, the graft-to-bone fixation strength biomechanically decreases the loosening of the soft tissue reconstruction over time. This additional fixation strength[31,32] obviates the need to anchor the reconstruction to the distal radius (as in the original Brunelli's technique) or tether the graft to the dorsal radiolunatetriquetral ligament[11,13,15] or the ulnocarpal ligament[14] for tensioning. In this way, combined with the use of tenodesis screw, our construct holds similarities with that tested by Eng et al;[30] differences are the use of a tendon autograft rather than a synthetic replacement device and the placement of the tenodesis screw in the scaphoid rather than the capitate. We believe these differences may hold advantages for surgeons who may want to avoid the additional costs associated with the use of synthetic ligaments and who prefer a bone–tendon fixation site that is near to the site of

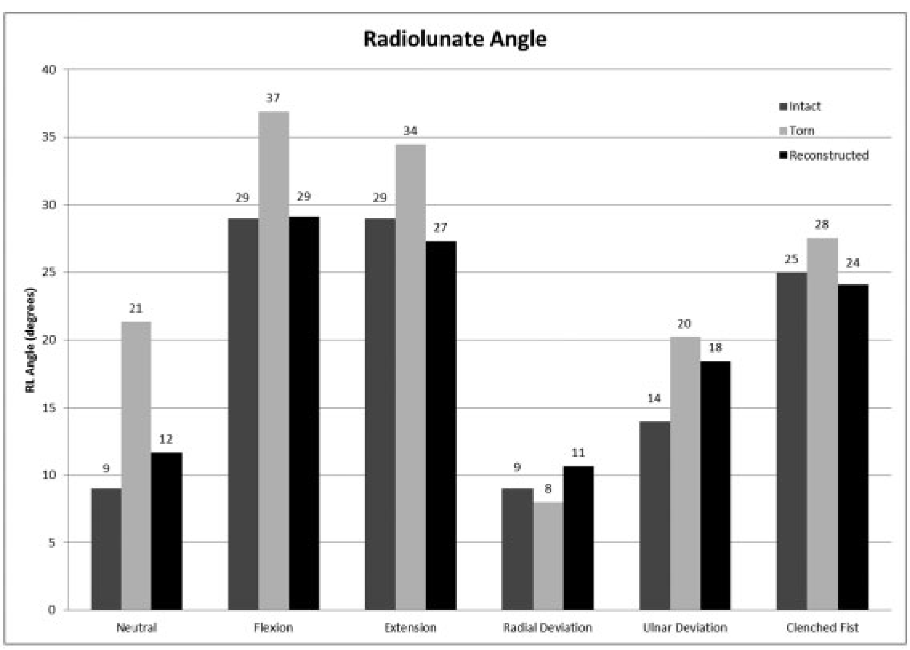

Fig. 5 Average radiolunate angle for all conditions and testing positions (degrees).

attachment of an intact scapholunate ligament. Because both techniques obviate a tethering effect to the distal radius, we anticipate that postoperative ROM may be improved. While this study was not designed to perform a biomechanical comparison with other surgical techniques, our results show that static stability of the SL joint was measurable and achieved.

The second advantage is the ability to incorporate the volar aspects of the SLIL. While the importance of the dorsal component of the SLIL has been demonstrated in prior biomechanical work,[16] the stabilizing role of the volar SLIL has recently been reexamined. Biomechanical studies have demonstrated that the volar portion may contribute approximately half of the tensile force of SLIL[17] and may be particularly important for restoring sagittal stability,[19] providing justification for recent enthusiasm to repair or reconstruct the volar SLIL.[20,21] Additionally, because the volar portion of the SLIL is under greater strain during axial loading with the wrist extended,[18] inclusion of the volar aspect of the SLIL during reconstruction should help in restoring performance measures such as grip strength. A secondary advantage of this technique is the avoidance of using an FCR graft, as it can be reeducated to aid treatment of dynamic scapholunate instability.[33]

Other transosseous ligament reconstruction techniques, such as bone–ligament–bone[34] and bone–retinaculum–bone reconstruction,[35] RASL procedure,[8] and the SLAM,[9] are based on a similar premise of orienting the graft reconstruction in a manner that provides multiplanar control of the scaphoid. These techniques intend to decrease scapholunate diastasis and control scaphoid flexion, addressing limitations of prior techniques (such as capsulodesis) that control motion in one plane only.

Technical aspects about the reconstruction deserve consideration. It is as challenging as others, and we recommend practicing on a cadaver before trying in vivo. The key technical point is careful placement of the guide wires for the cannulated drill so that the tendon is retrievable in the volar wound without fracture of the tunnel. Early attempts at SLIL reconstruction were conceptually similar to our technique with a tendon graft passed through scaphoid and lunate tunnels to provide a tight link between these bones,[36,37] and the absence of an interference screw is a major point of difference. The poor long-term results from these earlier attempts were largely attributed to the risk of tunnel fracture and joint degeneration, given the need to drill large tunnels in scaphoid and lunate areas with relatively poor vascular supply.[24] While this is a valid concern for our technique, both the MBT and our technique include a single tunnel in the scaphoid with a nearly identical starting point along the dorsal surface of the proximal scaphoid. Given the devastating nature of tunnel fracture, it is critical to ensure appropriate positioning of the drills prior to tunnel creation. The modification of Brunelli's technique with the best long-term results includes the insertion of a large scapholunate reduction screw,[12] which may also increase the risk of vascular compromise. The MBT is not without the risk of similar sequelae, with De Smet and Hoonacker reporting a case of scaphoid osteonecrosis after MBT.[14] We believe that the technical advances of the interference screw, particularly the enhanced ability to secure the soft tissue graft into bone, provide advantages, which render this type of SLIL reconstruction a practical alternative. Another theoretical concern about our reconstruction technique is the potentially decreased ability to control sagittal motion of the scaphoid, as the reconstruction does not pass through the distal pole of the scaphoid. However, Dunn and Johnson demonstrated that SL sagittal stability only improved after addressing both the volar and dorsal SLIL components (and not after only repairing the dorsal SLIL).[19] This suggests that incorporating the volar SLIL into the reconstruction may provide sufficient sagittal plane stability.

This study has several limitations. As a cadaveric study, the results presented here reflect initial "time zero" results and cannot account for the effect of postoperative healing and scar tissue formation on SL relationships and wrist motion. Additionally, we attempted to produce static SL instability by sharply transecting the entire SLIL and volar radioscaphocapitate ligament, but the controlled testing environment cannot reproduce the extent and type of damage caused after acute injury or chronic degeneration. Similar to this is how the forces needed to recreate certain wrist positions were greater than that reported by Pollock,[25] and that this finding underscored both the inherent challenge of reproducibility between independent laboratories and the inability of cadaveric biomechanical testing to replicate in vivo states. With greater loads needed in our testing versus those used in Pollock's study, it is possible that our apparatus produced results that underestimate the physiologic strength of the reconstruction; we believe that this may have resulted in forces that not only near but also exceed physiologic loads.

Finally, our results are based solely on fluoroscopic images, reflecting static relationships and cannot account for the influence of dynamic wrist stabilizers and secondary carpal stabilizers on the complex SL relationship. While the design of the study reliably produced static coronal plane SL instability (reflected by SL interval increase in all wrist positions), it was less successful in producing sagittal plane instability (reflected by the absence of SL angle changes in extension, UD, and clenched fist and the absence of RL angle changes in RD and clenched fist). We partially attribute this lack of consistent angle changes to variability of the contributions of secondary SL stabilizers among specimens. Alternatively, it is assumed but has never been proven that SL diastases always and exclusively correlate with abnormalities in SL and RL angles. Nevertheless, the decreased magnitude of SL instability made it more difficult to demonstrate a difference among the testing states. This may render a more conservative view of the reconstructive technique's ability to restore stability.

In conclusion, this study demonstrates significant improvement in SL angle in flexion, RD, and UD. Our data suggest that this technique sufficiently restores static scapholunate relationships and warrants further investigation.

Note

Institutional ethical board review approval was obtained from the IRB of the Hospital for Special Surgery. The work was performed at the Hospital for Special Surgery.

Conflict of Interest
None.

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